

Continuously Reinforced Concrete Pavement (CRCP) Design and Construction Guide

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1.0 PURPOSE OF THIS GUIDE

The purpose of this Guide is to provide Caltrans and consultant pavement engineers with a uniform, streamlined process for designing continuously reinforced concrete pavements on Caltrans-approved projects. The Guide also addresses related topics that the pavement engineer needs for making effective pavement decisions. As a part of this guide, appropriate figures were obtained from Concrete Reinforcing Steel Institute (CRSI). References used are superscripted in the document and are listed in Section 11.

2.0 DESCRIPTION

A Continuously Reinforced Concrete Pavement (CRCP) is one type of rigid pavement, also referred to as Portland Cement Concrete Pavement (PCCP) with reinforcing steel and no transverse joints. CRCPs are reinforced in the longitudinal direction, and additional steel is also used in the transverse direction to hold the longitudinal steel in place (see Figure 1). The longitudinal bars are lap spliced so that continuity of the steel is maintained, ensuring good performance of the pavement (see Section 4.2.1 for this topic). Due to the continuous reinforcement in the longitudinal direction, the pavement develops transverse cracks spaced at close intervals. These cracks develop due to changes in the concrete volume, restrained by the longitudinal reinforcement steel, resulting from moisture and temperature variation. Crack width can affect the rate of corrosion of the reinforcing steel at the crack locations when water or de-icing salts (if used) penetrate the cracks. In a well-designed CRCP, the longitudinal steel should be able to keep the transverse cracks tightly closed and minimize water penetration.



Figure 1: CRCP Longitudinal and Transverse Reinforcements

The optimum amount of longitudinal reinforcement steel in the standard plans is determined such that it satisfies all of the following three limiting criteria:

- Cracks spacing: In order to minimize the potential of concrete punchout and spalling, the spacing between consecutive cracks must be limited between 3.5 ft (to limit punchout) and 8.0 ft (to limit spalling)¹.

- Cracks width: In order to minimize spalling, water infiltration and load transfer, the allowable crack width should not exceed 0.04 in.
- Steel stress: In order to prevent steel yielding and excessive permanent deformation, the tensile stress in steel is limited to no more than 75% of its ultimate tensile strength.

3.0 BENEFITS AND APPLICATIONS

A number of benefits could be gained from using CRCP for the construction of highways. They include:

- Less maintenance required, thus reducing the need for future maintenance closure.
- Lower maintenance cost because there are no transverse joints to maintain.
- Reduced water penetration because there are fewer joints and tighter transverse cracks.
- Smoother pavements over time since there are no transverse joints.
- Lower long-term life cycle cost despite potential higher initial cost.
- Ability to handle heavier truck loading and volumes.

There are situations, however, where CRCP may not be desirable:

- For conventional highways, local roads, and areas where there are utilities underneath the roadbed. Accessing (digging up) to maintain these utilities can damage the CRCP.
- For parking areas since CRCP is expensive to build for lightly trafficked locations

The Department's policy is to use CRCP for rigid pavements where it is determined to be cost-effective. Life cycle cost analysis (LCCA) is the most effective means to help make such determination. The Department's Pavement website at <http://www.dot.ca.gov/hq/esc/Translab/OPD/DivisionofDesign-Pavement-Program.htm> provides information on performing LCCA.

4.0 COMPONENTS OF CRCP

A typical CRCP is constructed of concrete, steel bars, and joints. In the following, a brief discussion of each of these components will be presented along with necessary aspects for their design.

4.1 Concrete

Concrete is an artificial stone-like material used for various structural purposes. It is made by mixing cement, sand, and various aggregates such as pebbles, gravel, and shale, with water and allowing the mixture to harden by hydration. Cement in concrete acts as a primary binder to join the aggregates into a solid mass. Like Jointed Plain Concrete Pavement (JPCP), CRCP is constructed using Portland Cement Concrete (PCC) except that aggregates used must have coefficient of thermal expansion of $6.0 \times 10^{-6} / F^{\circ}$ or less. Section 40 of the Standard Specification covers general concept in PCC pavement construction, **Section 90-1 of the Standard Specification** covers the types, classes, and strength of PCC; and **Section 90-2** covers the specified materials necessary to produce the PCC.

4.2 Steel

CRCP contains both longitudinal and transverse steel. Deformed steel bars used are those that meet the requirements set out in **Section 52: Reinforcement** in the Standard Specifications. The use of epoxy-coated reinforcing bar is not necessary for CRCP², except in areas where corrosion is known to be a problem (e.g., because of the presence of salts or the application of de-icing salts). In California, epoxy coating should be used in high desert and all mountain climate regions (See California climate map on the Pavement website at http://www.dot.ca.gov/hq/oppd/pavement/Pavement_Climateregions_100505.pdf), and when the project is within half a mile distance from a salt-water body. In the following, both longitudinal and transverse steel as well as steel tie bars are discussed.

4.2.1 Longitudinal Reinforcement

The function of the longitudinal steel is to strengthen the concrete, to control concrete volumetric changes due to temperature and moisture variations, and to keep transverse cracks tightly closed. If the steel is able both to serve its function (i.e., reinforcement) and to keep cracks from widening, the aggregate interlock (i.e., the mechanical locking that forms between the fractured surfaces of concrete along any transverse crack) will be preserved and stresses in the concrete due to traffic loading will be reduced.

Longitudinal reinforcement steel used for CRCP consists of Grade 60 No. 6 steel bars, spaced at 5.5 to 9.0 inches center-to-center³. The recommended position of the longitudinal steel is 4.0 inches from the surface of the concrete to the top of reinforcement bars (see Standard Plan P4) except for thicknesses greater than .95-foot where slightly deeper cover is needed so that the transverse bar is not cut by the joint saw.

Maintaining steel continuity in the longitudinal direction in CRCP ensures good performance of the pavement. The continuity of the steel is achieved by overlapping each steel bar. A staggered splice pattern as shown in the schematic drawing in Figure 2 is recommended for splicing longitudinal steel. A minimum lap length of 45 diameters of the smaller bar joined (34 –inches for #6 longitudinal bar), and a minimum clear distance between staggers should be the same as the length required for a lap splice of the largest bar⁵. Requirement for reinforcement splicing can be found in **Section 52-1.08 in the Standard Specification**. Additional longitudinal reinforcement is placed at transverse contact (construction) joint to ensure sufficient reinforcement at points of discontinuity (see Section 4.3 on this and other types of joint used in CRCP).

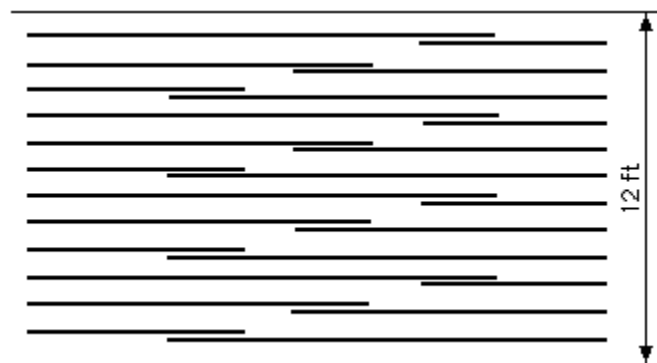


Figure 2: Staggered Lap Splice

4.2.2 Transverse Steel

Transverse steel is used across the entire width of CRCP lanes primarily to support the longitudinal reinforcements during construction, and to tighten and reduce the risk of occurring and opening-up of random longitudinal cracks, thus reducing the potential of punchouts. Longitudinal cracks occur approximately parallel to the centerline of the pavement. Additionally, transverse steel is used to tie adjacent lanes together across weakened plane joints (see Section 4.3 for this type of joint).

Transverse steel is usually Grade 60 No. 6 deformed steel bars spaced at 12.0 to 36.0 inches center-to-center depending on the pavement width.

4.2.3 Tie Bars

Tie bars are deformed 50-inch long, epoxy-coated Grade 60 No. 6 steel bars, placed in the same plane as transverse reinforcement and perpendicular to the longitudinal joint to hold the faces of abutting concrete in contact, and to help develop interlock along these joints. Tie bars are typically used at longitudinal contact joints or between an edge joint and shoulder. The spacing of the tie bars is the same as that used for the transverse reinforcement bars.

The common method of tie bar placement is with a mechanical splice, as shown in Standard Plan P4. The Department does not allow the use of bent tie bars even though they could be straightened after placement of the concrete. This is because bending of tie bars causes them to lose their epoxy coating and in some cases causes the tie bars to break. It also causes the concrete to crack because of its brittleness.

4.3 Joints

Joints are vital to control cracking and horizontal movements of the pavement. Plain concrete pavements without joints would be riddled with cracks within one or two years after placement. Even with JPCPs, incorrectly placed or poorly designed joints will result in premature pavement cracking.

CRCPs do not contain transverse weakened plane joints like their JPCP counterparts. However, joints in CRCP include transverse contact joints (also known as construction joints), longitudinal contact joints, longitudinal weakened plane joints, and terminal joints. The Standard Plans should be consulted for the proper depth, width, line of the saw cut and type of seal required to construct these joints. In the following, the various types of joints commonly used in CRCPs are discussed.

4.3.1 Transverse Contact Joints

A contact joint (see Figure 3) is a joint formed when (i) concrete is placed at different times, or (ii) when paving is interrupted at the end of each day's paving operation, or (iii) the paving is interrupted for more than 30 minutes. An additional 42-inch long longitudinal reinforcement is placed in the transverse contact joint on the same plane and twice the distance as the longitudinal reinforcements³.



Figure 3: A Transverse Contact Joint Formed

Transverse contact joint should be planned so that they coincide whenever possible with terminal joints (see Section 4.3.4 for this type of joint) to eliminate extra joints.

4.3.2 Longitudinal Joints

Longitudinal joints (see Figure 4) are necessary to control cracking in the longitudinal direction due to warping, expansion and shrinkage stresses caused by temperature variations when concrete is placed in great widths. They are constructed at lane lines, typically in multiples of 12 feet. Where there are no lanes, longitudinal joints should be spaced 12 feet apart, but no more than 14 feet apart. When widened slabs are used, longitudinal joints are omitted at the edge of traveled way.



Figure 4: Longitudinal Contact Joint at Lane Line

4.3.2.1 Contact Joints

Joints between separately placed adjoining lanes are longitudinal contact joints. Tie bars (see Section 4.2.3) are used to tie the adjoining concrete placement together.

4.3.2.2 Weakened Plane Joints

A longitudinal weakened plane (contraction) joint is formed by saw-cutting concrete to a depth specified in the specification at lane lines or other locations specified on the plans. Weakened plane joints are held together by transverse steel reinforcement.

4.3.3 Terminal Joints

A terminal joint is used in CRCP to transition to another pavement type of differing design, or to a bridge structure, or to limit horizontal movement. Their function is primarily to (i) isolate adjacent pavement types or structures, and (ii) anchor the CRCP so that excessive horizontal movement does not occur that would otherwise damage the CRCP and the adjacent pavement or structure.

Terminal joints are provided and located at the beginning and end sections of CRCP used to accommodate longitudinal movement due to shrinkage or swelling caused by thermal variations so as to protect the abutting ends of CRCP and other pavements. Table 1 lists the types of terminal joints and where they can be used³. The various types of these joints are discussed briefly in the following sections.

Table 1. Terminal Joint Types

Joint Type	Where to Use it
Wide Flange Beam Terminal Joint	Use at all bridge approaches, transition between CRCP and other rigid pavements, and flexible pavements at grade of 4% or greater. Can use for any transition.
Terminal Joint-Type A	Use for any locations where CRCP abuts to existing flexible pavement.
Terminal Joint-Type B	Use for any locations where CRCP construction is terminated at a planned location.
Terminal Joint-Type C	Use for any locations where CRCP abuts to new or temporary flexible pavement.

4.3.3.1 Wide Flange Beam Terminal Joint

The wide flange beam terminal joint (see Figure 5) has been a standard practice used by many highway agencies to accommodate pavement end movements. The size of the wide flange beam is dependent on pavement thickness and truck traffic volume. Within the limits of wide flange pavement terminal installation, the subgrade should be prepared and compacted as specified in the special provisions in the same manner as the rest of the roadbed before additional layers of subbase and base are put on top of the subgrade³. Where expansive soil is encountered, **Section 614.4 of the Caltrans HDM** should be consulted in order to address this type of soil.

The wide flange beam is set partially into 10-foot long and 12-inch minimum thick sleeper slab³, which provides support for the CRCP and concrete pavement abutting at each end. In order to achieve long-term performance without significant repair, the design of the wide flange beam should consider: (i) allowable end movements of pavement, (ii) load transfer across the joint, (iii) the durability of the wide flange beam to resist corrosion effects, (iv) fatigue loading under heavy truck traffic, and (v) rigid connection to bridge side pavement⁶. These design considerations are explained below.

Since wide flange beam accommodates end movement, an expansion joint is usually needed (i) at the bridge approach slab, or (ii) between the wide flange beam and pavement end transition. Wide flange beam is susceptible to corrosion if placed in an environment near salt-water body or where there is an extensive use of de-icing salts. The use of galvanized beam is necessary to protect the beam from corrosion. As an alternative to galvanized beam, either epoxy coating or a wider or thicker flange beam may be considered¹. The use of thicker or wider flange can provide for improved resistance to fatigue-related failures under heavy truck traffic loading.

The wide flange beam can fail when the top flange separates from the beam web. So that rigid connection can be maintained and premature failure prevented, studs 0.75-inch in diameter and 8 inches long are welded to the flange bottom and the web spaced alternately at 9 inches and anchored to the concrete pavement end on the bridge side of the joint. This rigid connection can help maintain profile and cross slope at the joints over the service life.



Figure 5: Wide Flange Beam Terminal Joint

Standard Plans P32A and P32B contain the following information for wide flange beams:

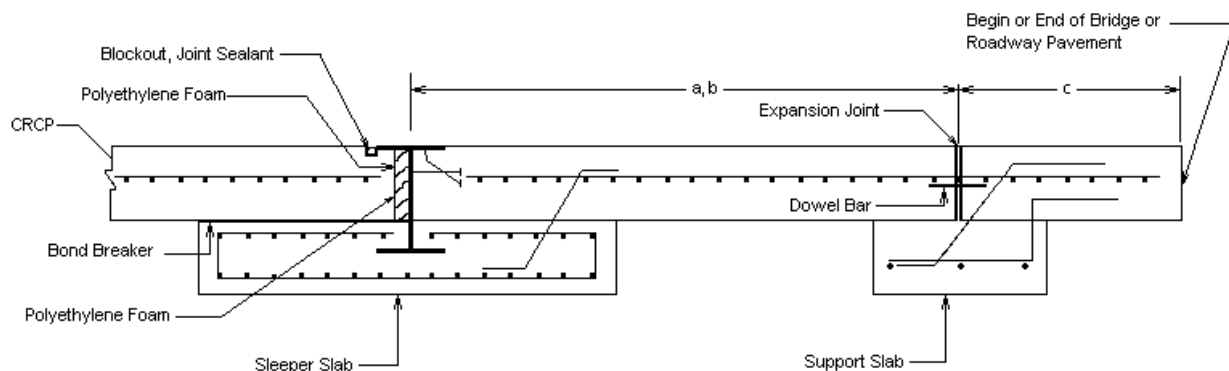
- Location of the wide flange terminal joint at bridge approaches and at transition pavements (rigid or flexible)
- Table of beam sizes with respect to pavement thicknesses.
- Dowel bar at expansion joint.

- Stud connection to wide flange beam.
- Bar sizes used in tying support slab to CRCP at expansion joint.

The following information for wide flange terminal joints should be shown in the plans:

- The location of the wide flange terminal joint by station.
- Pavement width, thickness, and crown cross-slope on typical sections.

Standard Plans P32A and P32B - “Continuously Reinforced Concrete Pavement – Wide Flange Pavement Terminal” show a wide flange terminal system to accommodate the movement at the joint between the abutting end of a CRCP on one side and end of the bridge, approach slab or another rigid pavement on the other side. Figure 6 shows a schematic drawing of wide flange beam terminal.



Notes:

a= 15 feet minimum at bridge.

b= 20 feet at concrete pavement end transition.

c=20 feet.

Figure 6: Wide Flange Beam Terminal Details

In conjunction with wide flange beam terminal joint, the expansion joint is provided to accommodate large expansion of pavement exceeding 0.50 inch. Where expansion joint is to be used, a sleeper slab beneath the joint is constructed to provide a large bearing area and to serve as a support for the free edges of the abutting concrete pavements. One inch of expanded polystyrene is placed over the slab support prior to placing the concrete to prevent bonding and to allow the pavement to move easily when it contracts and expands. The expansion joint width formed between the CRCP and a bridge, approach slab, or any other rigid pavement requires the Type B seal (1 ½ Movement Rating) as shown in Standard Plan B6-21. The Type B Seal is specified and paid for as a separate item of work in contract documents. At pavement transition, the expansion joint is not used where flexible pavement abuts to CRCP or other rigid pavement (see Standard Plan P30).

4.3.3.2 Type A, Type B, Type C Terminal Joints

Where CRCP begins or terminates at existing flexible pavement, Type A terminal joint is used³. The longitudinal reinforcement is terminated 2 inches from the construction joint where abutting

pavements occur. Two transverse contractions joints are formed by sawcuts made at 10 feet and 25 feet from the construction joint.

Where CRCP is terminated without adjoining pavement, Type B joint is used. At the terminal section of CRCP a 27-foot long by 10-foot thick slab is provided for end support of the CRCP. The support slab is tied to CRCP with Grade 60, No. 5 reinforcement so that good support is also provided for the future pavement. The end of CRCP is backfilled with soil and graded to 3:1.

Where CRCP terminates at new or temporary flexible pavement, terminal Type C joint is used. At the terminal section of CRCP a 27-foot long by 10-foot thick slab is provided for end support of the CRCP and new or temporary flexible pavements. The support slab is tied to CRCP with Grade 60, No. 5 reinforcement.

4.4 Pavement End Transition

Pavement end transitions are made up of different pavement materials constructed within the same lane. The pavement transitions can be concrete pavement abutting to approach slab or concrete pavement abutting to flexible layer pavement. The use of dowel-jointed pavement at pavement transition eliminates the use of pressure relief or expansion joint. When the pavement transition changes from flexible pavement to concrete pavement, the Department recommends a reinforced concrete wedge panel at the transition to reduce the damaging effect of impact loading at the transition (see the Revised Standard Plans RSP P30 for different types of pavement transition).

5.0 DESIGN OF CRCP

This section provides all information necessary for the pavement engineer to design a CRCP.

5.1 Design Life

Topic 612 of the Caltrans Highway Design Manual (HDM) discusses pavement design life. The HDM and this Guide recommend that CRCP be designed for a design life of 40 years. This life represents the optimum number of years that a CRCP should be expected to perform satisfactorily before reaching its terminal serviceability or reaching a condition that requires major rehabilitation.

5.2 Performance Factors

Performance factors for CRCP can be found in **Topic 622 of HDM**. The performance factors for a CRCP are different from those used with JPCP. Whereas JPCP performance is primarily based on cracking and joint faulting, CRCP performance is judged by punchouts (see Figure 4). Per **HDM Topic 622**, CRCP is designed to have no more than 10 punchouts per mile at the end of its pavement design life.

5.3 Design Thicknesses

To design a CRCP, **Topic 623 of HDM** contains information on the thickness of concrete surface layer, and the thickness and type of the base and subbase layers. These thicknesses can be used for new construction, reconstruction, widening, and lane replacement.

5.4 Other Design Considerations

5.4.1 Detailing

A CRCP should be accurately detailed on the project typical sections, layouts, and construction details. The pavement on the project plans and details should be defined as CRCP with the limits shown on the project layouts.

5.4.2 Shoulders

Two types of shoulders can be used with CRCP: tied rigid shoulder or widened traffic lane (see **HDM Index 625.4**).

5.4.2.1 Tied Rigid Shoulder

A rigid shoulder that is tied to the adjacent traffic lane with tie bars provides lateral support to that lane. In order to obtain the maximum benefit, the rigid shoulder should be built monolithically with the adjacent lane (i.e., no contact joints). For this reason, the shoulder cross slope should match the lane cross slope which may require a design exception. The structural section for the tied rigid shoulder should match the structural section of the adjacent traffic lane.

Tied rigid shoulders are the most adaptable and preferred type of shoulders when future widening is planned within the design life of the pavement, or when the shoulder is to be used temporarily as a bus or truck lane. When it is expected to be converted into a traffic lane in the future, tied rigid shoulders should be built to the same geometrics and pavement standards as the traffic lane.

5.4.2.2 Widened Lanes

Widened lanes are concrete panels that are 14-foot wide in place of the prescribed lane width constructed for the traffic lane adjacent to the rigid or flexible shoulder⁷. By striping the lane at 12 feet, the additional width becomes part of the shoulder width, which will keep the truck wheel path away from the longitudinal joint. In addition, it provides lateral support to flexible or rigid shoulder by means of reducing the stresses that can lead to spalling along the longitudinal joint.

6.0 CONSTRUCTION OF CRCP

This section provides an overview of the basic steps involved in CRCP construction; namely base, subbase and subgrade preparation, reinforcing bars placement, concrete placement, concrete consolidation, finishing, curing and jointing. These basic elements are common to both fixed form and slip form paving.

6.1 Subgrade, Subbase and Base Preparation

Pavements constructed without adequate subgrade, subbase and base preparation may fail prematurely because of inadequate support. Also, pavements constructed without adequate base and subbase preparation may not meet smoothness specifications and long-term pavement performance.

6.1.1 Subgrade Preparation⁵

The overall strength and performance of a pavement is dependent on many factors including the load-bearing capacity of the subgrade. Anything that can be done to increase the load-bearing capacity or structural support of the subgrade soil will most likely improve the overall strength

and performance of the pavement. Generally, greater subgrade structural capacity can result in more economical pavement structures. In order to provide maximum structural support, the subgrade soil must be compacted to a density of no less than 95% as specified in **Section 19-5.03 of the Standard Specifications**. If it is not, the subgrade will continue to compress, deform or erode after construction, causing undesirable pavement cracks and deformation. In order to achieve these densities the subgrade must be at or near its optimum moisture content (the moisture content at which maximum dry density can be achieved). Usually, compaction of in situ or fill subgrade will result in adequate structural support.

Subgrade soil can vary widely over a short distance. Poor subgrade can be described as expansive (plasticity index greater than 12 and R-value of less than 10). Necessary tests such as sieve analysis, plasticity index, and R-value should be performed. The engineer should determine the quality of the subgrade if it is structurally adequate. If the structural support offered by the in situ compacted subgrade is estimated to be inadequate, there are options that can be used. Organic and peat soils are compressible and should be removed and replaced with a better soil prior to placing the pavement structure. For example, lime may be used with expansive soils, cement with less plastic soils (plasticity index less than 10) and emulsified asphalt can be used with sandy soils. The binding characteristics of these materials generally increase the subgrade load bearing capacity.

Compaction of not less than 95% must be obtained for a minimum depth of 2.5 feet below finished grade for the width of the traveled way and auxiliary lanes including 3.30 feet on both sides as required in the Standard Specifications. The minimum depth of 2.5 feet can be waived in the following situations: a portion of a local road is being replaced with stronger pavement structure, partial depth reconstruction, presence of existing utilities are to be moved, and interim widening project is required on low volume roads, intersections, or frontage roads. Location where the 2.50 feet compaction depth is waived must be shown on the typical cross sections of the project plans⁷. Any imported borrow to replace soft or unsuitable material or use of subgrade enhancement fabric in construction should be identified and shown. There is no minimum California R-value required by the Standard Specification for imported borrows; therefore a minimum must be specified by Special Provision to cover the material placed within 4 feet of the finished grade.

6.1.2 Subbase Layer Preparation⁵

The subbase layer is a planned thickness of specified material between a base and the subgrade or basement material. Unbound aggregate or granular material primary purpose is for structural support, and other uses include (i) improve drainage, (ii) minimize frost action damage (iii) minimize intrusion of fines from the subgrade into the pavement structure.

The Department uses Class 2 Aggregate Subbase, as shown in **Table 623.1B to Table 623.1M in the Caltrans HDM**, for use in CRCP to provide a foundation or working platform for the base when placed on the subgrade. Aggregate may include any of the processed materials from reclaimed asphalt concrete (RAC) lean concrete base (LCB), cement treated base (CTB), portland cement concrete (PCC), or it consists of any combination of these materials, but the reclaimed material amount should be less than 50% of the total volume of the aggregate used.

Aggregate subbases are delivered as uniform mixes and deposited to the roadbed in layers or windrows, free from pockets of coarse or fine material and segregation should be avoided.

Spreading and compaction in one layer may be accomplished when the required thickness is 0.50-foot or less. Where the required thickness is more than 0.50-foot, spreading and compaction are in 2 or more layers of approximately equal thickness. The maximum compacted thickness of any one layer does not exceed 0.50 foot. Compaction of aggregate subbase is specified in **Section 25-1.05, “Compaction” of the Standard Specification**.

6.1.3 Base Layer Preparation⁵

The base layer is immediately placed beneath the surface course. It provides for additional load distribution and contributes to drainage (if permeable base is used) and frost resistance.

The Department uses Hot Mix Asphalt (HMA) (Type A) to provide a construction platform underneath the CRCP. HMA (Type A) provides a smooth base layer, and a good bond breaker layer. HMA (Type A) provides flexibility to expand and contract with temperature fluctuations.

HMA (Type A) base layer consists of a combination of mineral aggregates and asphalt materials mixed mechanically in a plant. It consists of one or more layers placed on a prepared subbase in conformity with the alignment and grades shown on the project plans. It is placed at a temperature of not less than 310 °F and only when the subbase surface is dry and in satisfactory condition. When required, a prime coat of liquid asphalt can be applied to the area of the subgrade or the subbase to receive the HMA base. Tack coat (paint binder) shall be applied between lifts of HMA base.

All loose material must be completely removed from the primed subgrade before placing HMA base. **Section 39-6-Spreading and Compacting** states that all breakdown compaction must be completed before the temperature of the HMA mixture falls below 200 °F. HMA (Type A) base is spread and compacted in a number of lifts. Layer shall be placed over a layer, which exceeds 0.20-foot in compacted thickness. The compacted thicknesses are 0.20-foot minimum and 0.40-foot maximum. In order to provide maximum structural support, the completed deep lift of asphalt base course shall have an average density of at least 98 percent of the laboratory density, based on the Job-Mix Formula for the asphalt mixture when tested in accordance with **California Test 304** and **ASTMD 1188**, **California Test 308**, or **California Test 375**.

6.2 Reinforcing Steel Placement

Proper placement of reinforcing steel is crucial to performance of CRCP. CRCP failures are usually associated with insufficient reinforcement bar lap splice, unconsolidated concrete around the steel, improper positioning of the steel in the slab and extreme hot weather during construction. Reinforcing steel for CRCP has been placed by two general methods: manual method or mechanical method. However, a number of states have found longitudinal steel placement not precisely spaced and deviations of ± 3 inches in the vertical plane when mechanical placement using tube feeders was employed to position the steel². The Department currently does not allow the mechanical method. Therefore, reinforcing steel shall be placed manually (see Figure 7) before the concrete is placed. The advantage of the manual placement method is that it allows for easy checking of bar placement, height and lap splice length. However, the manual method is slower and more labor intensive than the mechanical method.



Figure 7. Manual Placement of Reinforcing Steel

Since the transverse steel is placed 4.0 to 4.75 inch below the surface in the finished slab, small No. 4 metal chairs (welded to the transverse bars) or “plastic” chairs (tied to the transverse bars)⁸ must be used to support the top longitudinal reinforcing steel in order to achieve this elevation before concrete is placed. The metal chairs are positioned with its wide base perpendicular to the transverse bar; either type of chair is placed on the HMA base without fastener as illustrated in Figure 8. The chairs must be strong enough to hold the reinforcing steel in place during concrete placement, consolidation, and finishing.



Figure 8. Plastic Chair (Left) and Steel Chair (Right).

The typical placement process involves (i) placing the transverse bars on chairs, (ii) arranging the longitudinal bars on top, and then (iii) tying the longitudinal bars to the transverse bars. Typically, longitudinal reinforcements are tied or clipped to the transverse bars every 1 to 3 feet. Figure 1 shows reinforcing bars in their final position just before concrete placement.

6.3 Concrete Placement

The placement of concrete in CRCP can be done using any equipment or procedure used to place concrete for JPCPs except that because reinforcing steel must be placed prior to placing the concrete, concrete delivery trucks are not allowed to end-dump in front of the paving machine. Therefore, drive over unloader and a belt placer machine which runs parallel and in front of the paver may be needed in paving. These are the same devices used when placing existing JPCP where it is not possible to end-dump in front of the paving machine (such as widenings where access to end-dump is limited or dowel bar baskets are used.)

The concrete truck comes behind the paver, drives on to the drive over unloader and dumps the concrete. The conveyor belt that is connected to the drive over unloader then places the concrete in front of the paver for forming. Use of these machines require a minimum 18 ft. wide alongside and right of the area to be paved for the drive over unloader use and for the haul truck to get in and out easily of the drive over unloader. Because of its size, the belt placer machine and drive over unloader are hard to moved or stored easily. Consolidation, finishing, curing, and jointing processes follow concrete placement, and they are briefly described below:

- Consolidation is the process that compacts fresh concrete to mold it within and around the forms and steel reinforcements and to remove voids. The consolidation requirement can be found in **Standard Specification 40-1.07A – Stationary Side Form Construction**
- Finishing involves any equipment or procedures used to impart the specified surface characteristics. The preliminary and final finishing requirements can be found in **Standard Specification 40-1.09 and 40.110.**
- Curing is the moisture and temperature in the concrete as it sets and hardens such that the desired properties can develop. The curing requirement can be found in **Standard Specification 90-7.02.**
- Sawing joints involves all sawing operations conducted on the pavement to create weakened plane joints, and longitudinal and transverse contact (construction) joints to insert appropriate joint seals. However, CRCP uses longitudinal reinforcing steel in order to limit the number of weakened plane (a.k.a. contraction) joints. Sawed joints should be cleaned as specified. Timing is a key factor in sawing weakened plane joints and should be done as soon as the concrete is capable of supporting the weight of the saw. Refer to **Caltrans Specification 40-1.08B(1) – “Sawing Method”.**

7.0 STANDARD PLANS

Table 2 lists Caltrans standard plans for use with CRCP, and can be found at the Caltrans internet website at http://www.dot.ca.gov/hq/esc/oe/project_plans/HTM/06_plans_disclaim_US.htm. Contact the Division of Design, Office of Pavement Design, for more detailed information about these plans.

TABLE 2: List of Related Standard Plans

Plan Sheet Number	Standard Plan Title	Description
P4	Continuously Reinforced Concrete Pavement	Use for new construction, reconstruction, widening, and lane replacement.
P9	Continuously Reinforced Concrete Pavement – Slab Replacement	For CRCP, it is used for all locations needing slab replacement. Plan shows where necessary saw cutting will be needed.
P10	Concrete Pavement – Dowel Bar Details	Use for all locations needing end panel pavement transition.
P18	Concrete Pavement - Lane Schematics and Isolation Joint Detail	Shows all general cases where isolation joints are to be located. Use on all new construction widening and lane replacement.
P20	Concrete Pavement-Joint Details	Use for all locations needing saw cutting. For CRCP, it is used for longitudinal joint and construction joint where saw cutting will be needed.
P31	Continuously Reinforced Concrete Pavement-Terminal Joint Details	Shows all general cases where terminal joints are to be located. This plan is used on new construction of future pavement, at existing asphalt concrete (AC) pavement, and for new AC and temporary pavement.
P30	Concrete Pavement-End Panel Pavement Transitions	Shows cases where end panel pavement transitions are to be located. This plan is used where concrete paving lane abuts to existing/new approach or sleeper slab or asphalt concrete pavement at transverse joint.
P32A and P32B	Continuously Reinforced Concrete Pavement-Wide Flange Terminals	Use for new construction of Wide Flange Beam Terminal between the end of CRCP and the ends of bridge, approach slab or other pavement types. Use with Standard Plan B6-21.
P34	Continuously Reinforced Concrete Pavement-Lane Drop Paving Details	Use for new construction, reconstruction, widening, and lane replacements at lane drops for CRCP.
P35	Concrete Pavement-Ramp Gore Area Paving Details	Use for new construction, reconstruction, widening of exit and entrance ramp gore areas next to CRCP.
P45	Concrete Pavement – Drainage Inlet Detail No. 1	Use for all drainage inlet locations needing isolation joints around concrete apron. When use in CRCP, transverse reinforcements are terminated 2 inches from all edges of longitudinal isolation joint.
P46	Concrete Pavement – Drainage Inlet Detail No. 2	Use for all drainage inlet locations needing isolation joints around concrete apron. When use in CRCP, transverse reinforcements are terminated 2 inches from all edges of longitudinal isolation joint.

B6-21	Joint Seals (Maximum Movement Rating = 2)	Use for construction of Wide Flange Beam Terminal with expansion joint requiring Type B Joint Seal. (MR = 1 ½). Use with Standard Plan P32A and P32B.
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8.0 STANDARD SPECIAL PROVISIONS (SSPs)

Table 3 lists some pavement CRCP related Standard Special Provisions that may be used by the pavement engineer on CRCP projects. The Division of Design pavement website at <http://www.dot.ca.gov/hq/oppd/pavement/ssps.htm#materials> is also a good source of information for CRCP design.

TABLE 3. CRCP Related Standard Special Provisions

SSP#	SSP Title	Comments
40-CRCP	Continuously Reinforced Concrete Pavement	Special Provision for use in the construction of all CRCP projects.
40-200	Shoulder Rumble Strips (Portland Cement Concrete, Rolled-In Indentations)	Use when rumble strips are to be constructed in new PCC pavement. If stage construction prohibits forming the rumble strips in the new concrete pavement because of stage construction patterns, use SSP 40-210.
40-200	Seal Existing Concrete Pavement Joint	Use for projects where new joint seals are to be constructed in existing concrete pavement. Include Standard Plan P20.
40-210	Replace Joint Seal (Existing Concrete Pavement)	Use for projects where existing pavement joint seals in concrete pavement are to be removed and replaced. Include Standard Plan P20.

9.0 COST ESTIMATION

The Table 4 below shows approximate volume of concrete and steel reinforcement weight per lane-mile of CRCP. Because there is no historical cost data available for CRCP, the following equation has been developed for estimating the cost per cubic yard of CRCP (\$/CY).

$$\text{Unit cost of CRCP} = 0.90 \times [\text{unit cost of JPCP } (\$/\text{CY})] + [\text{Weight of steel reinforcement (lb/CY)} \times \$0.65/\text{lb}]$$

TABLE 4

Thickness of Pavement	Weight of Steel Reinforcement per lane-mile
ft	lbs / cy
0.80	15,666
0.85	15,451
0.90	15,451

0.95	15,451
1.00	15,120
1.05	15,484
1.10	15,328

This equation is based on a cost estimating procedure similar to that used for JPCPs except that there are no transverse joints or dowel bars. There is an added cost for the reinforcing steel.

The cost of wide flange pavement terminal measured transversely in linear foot should be estimated separately. It is estimated that the average cost in installing wide flange terminal joint is \$750 per linear foot quoted from Texas DOT statewide average price dated August 2006 and adjusted for California prices. The payment will be full compensation for all steel beams, stiffener plates, end plates, drilled holes, welding, cutting, styrofoam, joint filler, concrete, reinforcement, bond breaker, and for all material, labor, equipment, tools, and incidentals necessary to complete the work. Lean concrete base, hot mixed asphalt, aggregate subbase, and other base materials are paid for separately.

Terminal joints Type A, B and C must also be included in total cost when included in the project plans. These three types of joints are measured and paid for in cubic yard of concrete. The estimated average cost of each terminal joint Type A, B or C is 2 to 2.5 times the cost per cubic yard of concrete of CRCP. The payment will be full compensation for all welding, cutting, styrofoam, joint filler, concrete, reinforcement, and for all material, labor, equipment, tools, and incidentals necessary to complete the work.

10.0 MEASUREMENT AND PAYMENT

The quantity of CRCP is measured and paid for by the cubic yard of concrete including furnishing and placing the longitudinal reinforcements, transverse steel and tie bars. The volume of concrete is calculated based on the width, thickness and length shown on the project plans. Terminal joints are paid for separately.

11.0 REFERENCES CITED

This Guide was developed with the help from the information provided in the following documents:

- 1) "CRC-Highway Pave, Design of Continuously Reinforced Concrete Pavement for Highways", B. Frank McCullough, June 1993, a publication of CRSI.
- 2) "Technical Advisory, on "Continuously Reinforced Concrete Pavements", June 5, 1990 of the Federal Highway Administration.
- 3) "Standard Plans of the Texas Department of Transportation, a publication of Texas Department of Transportation
- 4) "Pavement Design Guide of the Texas Department of Transportation.

- 5) “Standard Specifications, May 2006”, a publication of California Department of Transportation.
- 6) “Terminal Treatment for Continuously Reinforced Concrete Pavement, August 2003”, a report prepared by Construction Laboratories, Inc
- 7) “Highway Design Manual” of the California Department of Transportation.
- 8) “Construction of Continuously Reinforced Concrete Pavement, 1993”, a publication of CRSI
- 9) “Figures used in this guide”, courtesy of Concrete Reinforcing Steel Institute (CRSI).